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ATTACHMENT 1
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3rd Interim Report
Self-Induced Transparency in Photonic Band Structures: Gap Solitons Near Absorption Resonances

We show that pulse transmission through near-resonant media embedded within periodic dielectric structures can produce self-induced transparency (SIT) in the band gap of such structures. This SIT constitutes a principally new type of gap soliton.

Pulse propagation in a non-uniform resonant medium, e.g., a periodic array of resonant films, can destroy self-induced transparency (SIT) [1], because the pulse area is then split between the forward and backward (reflected) coupled waves, and is no longer conserved [2]. Should we then anticipate severely hampered transmission through a medium whose resonance lies in a reflective spectral domain (photonic band gap) of a periodically-layered structure (a Bragg reflector)? We have shown analytically that it is possible for the pulse to overcome the band-gap reflection and produce SIT in a near-resonant medium embedded in a Bragg reflector. The predicted SIT propagation is a *principally new type of a gap soliton*, which does not obey any of the familiar soliton equations, such as the non-linear Schrödinger equation (NLSE) or the sine-Gordon equation. Its spatio-temporal form and intensity dependence are shown here to be distinct from the extensively – studied gap solitons in Kerr–non-linear Bragg reflectors [3], which are described by the NLSE.

In treatments of bidirectional field propagation in media with arbitrary spatial distribution of near-resonant atoms [4], the Bloch equations for the population inversion and polarization are entangled in a fashion which leads to an infinite hierarchy of equations for successive spatial harmonics. Here we avoid this complication by confining the near-resonant two-level systems (TLS) to layers much thinner than the resonant wavelength, with the same periodicity as the dielectric structure.

Our main idea has been to try the following phase-modulated 2π–soliton SIT solution for the envelope of the forward (F) and backward (B) field

$$E_{F(B)} = \frac{\hbar}{2\mu\tau_c}\left(1 \pm \frac{1}{u}\right) A_0 \frac{\exp\left[i(\alpha n_0 z/c\tau_c - \Delta t)\right]}{\cosh\left[\beta(z/\tau_c c u - t)\right]} \tag{1}$$

where μ is the transition dipole moment, τ_c is the cooperative (resonant) absorption time, A_0 is the amplitude of the solitary pulse, u is the velocity (normalized to c), n_0 is the mean refractive index and Δ is the field detuning from the gap center.

We focus here on the most illustrative case, when the TLS resonance is exactly at the center of the optical gap. Then the phase modulation α, the pulse inverse-width $\beta = A_0/2$ and the detuning Δ are analytically obtainable as a function of the group velocity cu. We find that the condition for SIT is that the cooperative *absorption length* $c\tau_c/n_0$ should be *shorter than the reflection* (attenuation) *length* at the gap $1/\kappa$, i.e., that the incident light should be absorbed by the TLS before it is reflected by the Bragg structure. SIT is found to exist only on one side of the band-gap center, depending on whether the TLS are embedded in the region of higher or lower linear refractive index in the Bragg structure. This result may be understood as the addition of a near-resonant non-linear refractive index to the modulated index of refraction of the Bragg structure. When this addition compensates the linear modulation, then there is no band gap and soliton propagation is possible. The soliton amplitude dependence on frequency detuning from the gap center (which coincides with the TLS resonance) is shown in Fig.1. The parameters obtained from our analytical solutions fully agree with those which yield both forward and backward soliton-like pulses in a numerical simulation of Maxwell-Bloch equations (Fig.2).

An adequate system for experimental observation of this effect appears to be a periodic array of 12-nm–thick GaAs quantum wells ($\lambda = 806$nm) separated by $\lambda/2$ non-resonant Al-GaAs layers. Area density concentration $\sigma \sim 10^8$–10^9 cm^{-2} of the quantum-well excitons yields $\tau_c \simeq 10^{-13}$–10^{-14}s. A solitary pulse of $\lesssim$ 1ps, i.e., much shorter then the dephasing time $T_2 \sim 10$ps (at 2^0K) in this structure requires band-gap reflection length $1/\kappa \gtrsim 100\ \lambda$.

The salient advantage of the predicted near-resonant gap soliton is stability with respect to absorption. By contrast, strong absorption is a severe problem associated with a large Kerr coefficient required for NLSE gap solitons [3].

[1] S. L. McCall and E. L. Hahn *Phys.Rev* **183**, 457 (1969); A. I. Maimistov et al. *Phys.Rep.* **191**, 2 (1990)
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[4] M. I. Shaw and B. W. Shore *JOSA B* **8**, 1127 (1991); R. Inguva and C. M. Bowden *Phys.Rev.A* **41** , 1670 (1990)

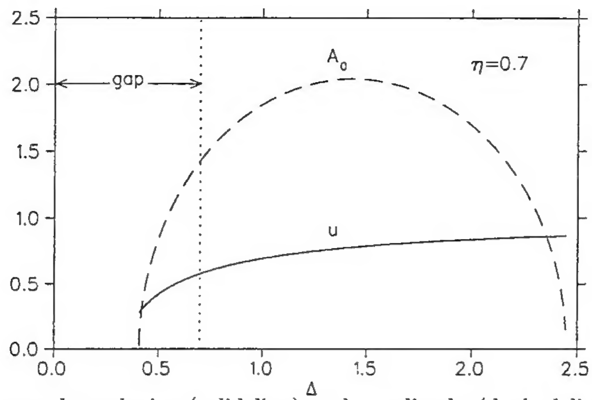

FIG. 1. Dependence of the solitary pulse velocity (solid line) and amplitude (dashed line) on frequency detuning from the gap center for $\eta = 0.7$. At the gap edge (dotted line) $u = 1/\sqrt{3}$ and $|E_F|/|E_B| = (\sqrt{3}+1)/(\sqrt{3}-1)$.

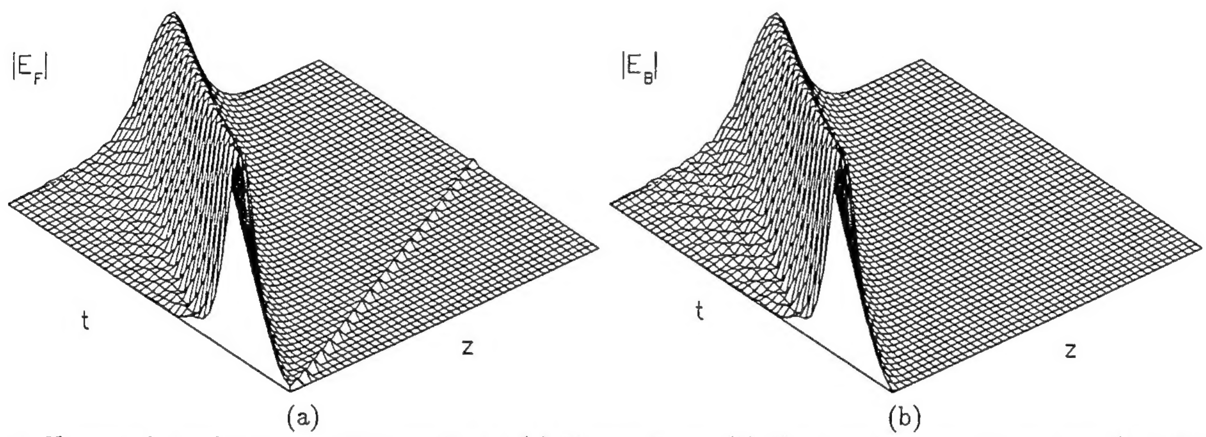

FIG. 2. Numerical simulations of the intensities of (a) "forward" and (b) "backward" waves in the gap. ($\eta = 0.7$, group velocity $u \sim 0.3$).

I. PAPERS SUBMITTED FOR PUBLICATION (PARTIAL SUPPORT BY USARDSG):

1. B. Sherman, A. G. Kofman and G. Kurizki "Preparation of nonclassical field states by resonance fluorescence in photonic band structures", *Appl.Phys.B* (in press)
2. A. Kozhekin and G. Kurizki "Self-induced transparency in Bragg reflectors: Gap Solitons near absorption resonances", *Phys.Rev.Lett* (submitted)
3. Y. Japha and G. Kurizki "Superluminal delays of coherent electromagnetic pulses: a universal mechanism", *Phys.Rev.Lett* (submitted)

II. STATUS OF RESEARCH PROJECTS FOR THE REMAINDER OF THE CONTRACT PERIOD:

1. Fock-state generation in photonic band structures: completed.
2. Nonadiabatic periodic interactions in photonic band structures: in progress.
3. Self-induced transparency (gap solitons) in photonic band structures: completed.
4. Lasing without inversion and electromagnetically induced transparency: in progress.